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OF STUDS FROM SMALL PONDEROSA PINE LOGS(U) FOREST
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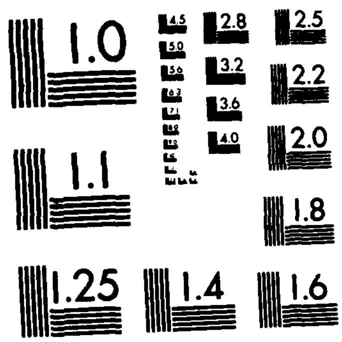

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An Evaluation of Saw-Dry-Rip (SDR) for the Manufacture of Studs from Small Ponderosa Pine Logs

Robert R. Maeglin and R. Sidney Boone

Abstract

Data show that the saw-dry-rip (SDR) method produces higher yields of STUD grade material than is produced by conventional sawing and drying or than has been produced in other studies using young-growth ponderosa pine. The studs are also more stable.

Small logs were live sawn into flitches. The flitches were kiln-dried and then ripped into studs for planing. The SDR treatment with high temperature drying resulted in 77.8 percent of studs so produced meeting the STUD grade after 30 or more days of storage.

Juvenile wood, compression wood, and less than optimum drying are discussed relative to problems yet remaining in the manufacture of studs from small ponderosa pine logs.

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An Evaluation of Saw-Dry-Rip (SDR) for the Manufacture of Studs from Small Ponderosa Pine Logs

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Introduction

Sawmill operators throughout the commercial range of ponderosa pine are increasingly interested in utilizing young growth, black bark, or "black jack" ponderosa pine (trees less than 100 years old and having black-colored bark). However, lumber sawn from these trees warps excessively after it is graded and shipped. The study reported here was undertaken at the Forest Products Laboratory to determine if the saw-dry-rip (SDR) process would reduce warp in pine studs.

Black jack ponderosa pines are mostly small (6- to 12-in. diameter at breast height (d.b.h.), contain large proportions of juvenile wood *(22)*,[2] and are prone to have compression wood *(2,21)*. Structural lumber, specifically studs, sawn from black jack pine may be graded and sold at 19 percent moisture content. But, as the lumber dries below 19 percent moisture content, it often warps beyond grade limits, even to the point of becoming cull material. The excessive warping problem is a plague to manufacturers, wholesalers, retailers, and consumers alike.

Several years ago, Arganbright et al. *(1)* in an effort to overcome the warp problem with black jack ponderosa pine compared different drying schedules with and without top loading. The best combination, conventional kiln drying and 200 lb/ft^2 top loading, resulted in 67 percent of the studs cut meeting the STUD grade based on warp. STUD is a specific lumber grade established by the National Grading Rule of the American Lumber Standards Act PS-20-70. The remainder were ECONOMY grade or cull.

In a similar study on black jack pine, Blake and Voorhies *(3)* evaluated four elevated or high-temperature kiln schedules for their effect on stud warp. Their best combination was an elevated temperature schedule (190° F) with 112 lb/ft^2 top loading. The treatment yielded 45.4 percent STUD grade pieces based on warp.

Both authors demonstrated that more warp occurred at lower moisture contents. The lumber manufactured by Arganbright et al. *(1)* had an average final moisture content of 15 percent, while that manufactured by Blake and Voorhies *(3,4)* had an average final moisture content of 12 percent. This variation in moisture content may account for the roughly 20 percent difference in acceptable, STUD grade pieces between the studies.

Mills cutting and drying second growth ponderosa pine studs to 19 percent moisture content often have difficulties with their product when it is shipped to and used in locations of low humidity. Such studs shipped to locations in the desert southwest are most prone to severe degrading warp. Arganbright et al. *(1)* note that some mills record warp-caused grade reduction, as high as 60 percent.

The SDR system of stud manufacture was conceived, by scientists at Forest Products Laboratory in 1978, for use with hardwoods because of longitudinal growth stress problems. It was devised to control excessive warping in studs which has kept low and medium density hardwoods from being used commercially for structural lumber. The success of SDR in manufacturing studs has been documented for yellow-poplar *(10,16)*, and aspen *(17,18)*. The promise for other species has also been explored, e.g., cottonwood, sweetgum, black gum, and sycamore *(19)* as well as basswood, soft maple, willow, red alder and paper birch.

A comparative study of SDR and conventional processing of yellow-poplar (a hardwood), showed reductions of 40 to 80 percent in average twist, bow, and crook for studs manufactured using SDR. Pieces making STUD grade were 100 percent for SDR with high-temperature drying and 98.3 percent for SDR with conventional drying *(16,19)*. A noncomparative study of aspen SDR studs showed 99.7 percent of studs manufactured met the STUD grade, based on warp, initially after manufacture. After at least 60 days storage in an open-sided shed under ambient conditions, 94.6 percent of pieces still made STUD grade *(18,19)*.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italicized numbers in parentheses refer to literature cited at end of this report.

Materials and Methods

Scope

This study was designed to evaluate the effect of SDR on the quality and yield of studs from small (5- to 12-in. diameter inside bark (d.i.b.) ponderosa pine logs. Increasing the yield and quality of graded studs from this resource could enhance the product recovery from logs and reduce the drain on the resource, allowing more trees to mature.

Design

The design for this study was a 2 by 2 by 2 factorial, using two sawing methods, two drying methods, and two sampling locations.

The two sawing methods were as follows:

- Conventional (C)
- SDR live-sawing (S)

The two drying methods were as follows:

- Conventional (C)
- High temperature (H)

These are combined in two-letter combinations where the first letter is the sawing method and the second is drying method:

- CC = conventional-sawing/conventional-drying
- CH = conventional-sawing/high-temperature-drying
- SC = SDR live-sawing/conventional-drying
- SH = SDR live-sawing/high-temperature-drying

To avoid sample loss should a kiln malfunction during drying, two replications of each combination were used, table 1.

Table 1.—2 by 2 by 2 factorial study design for studying ponderosa pine studs

Sawing method	Site 1				Site 2			
	Conventional drying		High temperature drying		Conventional drying		High temperature drying	
	Number of logs							
Conventional	10	10	10	10	10	10	10	10
SDR live sawn	10	10	10	10	10	10	10	10

Sample size was established on the basis of yellow-poplar data. The desired limits for sampling were a detectable difference of 5 percent with a confidence of 95 percent. With a sample size of 20 logs per cell, the probability of detecting a 5 percent difference in stud acceptance is slightly greater than 95 percent.

Log Collection

One hundred sixty woods run logs from small ponderosa pine trees (8- to 12-in. d.b.h.) were equally selected from two different sites by personnel of the Coconino National Forest, Flagstaff, Ariz. Log length was 8.5 feet, and the top (merchantable) diameter was about 5-in. d.i.b. At the Forest Products Laboratory logs were segregated by site. Within each site grouping, logs were divided into 8 groups of 10 logs each by butt and upper logs, and diameter class (small end d.i.b., 4.6 to 5.5 in., 5.6 to 6.5 in.—11.6 to 12.5 in.). The diameter distribution among the eight groups was as balanced as possible. After the groups were separated, they were assigned to treatment by random selection.

Sawing

Two sawing methods were used; a conventional cant system and live sawing. The conventionally sawn studs were cut using the centered cant method and split taper sawing. A 4-in. cant was cut from the geometric center of the log, taking side boards off where the logs were large enough. The side boards were cut 1-3/4 in. thick. Both cants and side boards were ripped green into studs for drying. Side boards were ripped into 2 by 4, 2 by 3, and 2 by 2 for best utilization, with emphasis on 2 by 4's.

Live sawing (through and through on one plane) was used to produce 1-3/4-in.-thick flitches for SDR. Full taper sawing, cutting parallel to one of the outside faces of the log, was used, as was a minimum 4-in. opening face. The flitches were edged green to 1/2 in. wider than acceptable wane limits, and the presumed final edging line, to form a more compact and efficient kiln load.

Drying

Two drying schedules were used; a conventional schedule and a high-temperature schedule. Conventional drying of studs and flitches was done according to Forest Products Laboratory Schedule T5-A5S *(20)*, striving for a moisture content of 12 ± 3 percent.

Based on high-temperature-drying experience with hardwoods, literature on high-temperature drying of softwoods *(6,12-15)*, and several trials with ponderosa pine, a high-temperature schedule was developed. The schedule was 240° F dry bulb and 190° F wet bulb for 24 hours followed by 24 hours of equalizing at 200° F dry bulb and 188° F wet bulb (equalibrium moisture content 10 pct) and 16 hours of conditioning at 195° F dry bulb and 188° F wet bulb (equalibrium moisture content 12.5 pct) striving for an average moisture content of 12 ± 3 percent.

Ripping SDR-Studs

After kiln drying, the SDR flitches were straight line ripped to 2 by 4, 2 by 3, and 2 by 2 for best utilization with emphasis on cutting 2 by 4's.

Warp Measurement and Grading

After sawing, drying, and ripping, the studs were dressed to standard ALS (American Lumber Standards) *(23)* sizes and measured for warp (crook, bow, and twist). Crook is a deviation edgewise from a straight line drawn from end to end of a piece. Bow is deviation flatwise from a straight line drawn from end to end of a piece. Twist is a deviation flatwise, or flatwise and edgewise, in the form of a curl or spiral so that the four corners of any face are not in the same plane. Each piece was measured to the nearest 1/32 in. for the three types of warp.

Acceptance of studs was determined using the National Grading Rule for dimension lumber, STUD grade. Limits of warp for 2 by 4 and 2 by 3 are crook 1/4 in., bow 3/4 in., twist 3/8 in.; and for 2 by 2, crook 3/4 in., bow 3/4 in., and twist 3/16 in.

After initial measurement, the studs were stored in an open sided shed for 30 days or more and then remeasured.

Statistical Analysis and Data Processing
Conventional analysis of variance for factorially designed studies was used to evaluate the effects of sawing, drying, and location on the yield of acceptable studs from ponderosa pine.

Results and Discussion

General Results

General warp data are presented in table 2 for combined stud sizes (2 by 2, 2 by 3, and 2 by 4) and in table 3 for 2 by 4 only. Major differences in warp are primarily between CC and the other treatments. In table 4 we see that the only significant differences between treatments are for twist, where the difference is highly significant for both 2 by 4's and combined stud sizes. The Duncan's multiple range test (table 5) shows no difference for crook or bow between treatments, but significant differences between treatments for twist ($P=0.05$).

For 2 by 4's only, a significant difference is shown between the CC treatment and all other treatments. There is also a significant difference between the CH treatment and the SH treatment. There is no statistical difference between the SC and the CH treatment or the SC and SH treatments. For the combined stud sizes, there are statistically significant differences between all treatments. The difference between warp types and treatment are shown graphically in figures 1 and 2 for 2 by 4's and combined stud sizes respectively.

Means by warp type and treatment and improvement by treatment over the CC results are shown in table 6. For crook, improvements are from 6.4 to 15.3 percent; for bow, from 1.4 to 21.4 percent; and for twist, from 25.0 to 67.5 percent. The improvements for crook and bow are not significant, but a small change in average warp can lead to many more studs recovered. The values of twist are, however, of practical and statistical significance.

While the average warp values are of interest and concern, the important question is, how many pieces make the grade? The standard used in this study, as previously mentioned, was the National Grading Rule—STUD grade. This was based only on warp—not on knots, moisture content, or

Table 2.—Warp average, range,[1] and number of rejects by treatment and area. Initial measurement after machining. All stud sizes combined (2 by 2, 2 by 3, 2 by 4)

		Treatment[2,3]											
		CC			CH			SC			SH		
Area	Warp	Average	Range	Rejects	Average	Range	Rejects	Average	Range	Rejects	Average	Range	Rejects
		---1/32 in.---		No.	---1/32 in.---		No.	---1/32 in.---		No.	---1/32 in.---		No.
1	Crook	5.6	52	17	4.7	31	10	6.8	52	18	4.7	33	11
	Bow	6.4	31	3	5.9	22	0	8.1	82	6	5.8	29	2
	Twist	3.9	22	4	2.7	25	1	2.1	11	0	1.1	7	0
2	Crook	6.7	48	14	6.0	35	17	5.0	28	14	6.4	33	23
	Bow	8.4	34	4	7.2	30	4	6.0	27	2	6.2	36	4
	Twist	4.3	18	4	3.4	15	3	2.2	13	1	1.2	10	0
Combined	Crook	6.2	52	31	5.4	35	27	5.8	52	32	5.6	36	34
	Bow	7.3	34	7	6.5	30	4	7.2	82	8	6.0	36	6
	Twist	4.0	22	8	3.0	25	4	2.1	13	1	1.3	10	0

[1] Range is from 0 to value shown.
[2] CC = conventionally sawn/conventionally dried; CH = conventionally sawn/high temperature dried; SC = SDR live sawn/conventionally dried; SH = SDR live sawn/high temperature dried.
[3] Total number of samples per treatment: CC = 130, CH = 136, SC = 152, SH = 149.

Table 3.—Warp average, range,[1] and number of rejects by treatment area. Initial measurement after machining, for 2 by 4 studs only

		Treatment[2,3]											
		CC			CH			SC			SH		
Area	Warp	Average	Range	Rejects	Average	Range	Rejects	Average	Range	Rejects	Average	Range	Rejects
		---1/32 in.---		No.	---1/32 in.---		No.	---1/32 in.---		No.	---1/32 in.---		No.
1	Crook	6.4	52	17	5.1	31	10	7.3	40	14	5.1	33	8
	Bow	6.1	30	3	6.1	22	0	6.5	28	2	4.3	25	1
	Twist	3.9	14	3	3.0	25	1	2.6	11	0	2.0	7	0
2	Crook	8.4	48	11	7.3	35	17	6.2	28	13	7.2	33	21
	Bow	8.4	30	3	7.4	30	3	5.2	27	2	5.5	26	1
	Twist	4.9	18	5	3.7	15	3	2.8	13	1	1.5	10	0
Combined[3]	Crook	7.2	52	28	6.1	35	27	6.6	40	27	6.6	33	29
	Bow	7.0	30	6	6.9	30	3	6.1	28	4	5.5	26	2
	Twist	4.2	18	8	3.1	25	4	2.6	13	1	1.8	10	0

[1] Range is from 0 to value shown.
[2] CC = conventionally sawn/conventionally dried; CH = conventionally sawn/high temperature dried; SC = SDR live sawn/conventionally dried; SH = SDR live sawn/high temperature dried.
[3] Total number of samples per treatment: CC = 93, CH = 115, SC = 98, SH = 94.

Table 4.—Analysis of variance of warp for area treatment and log position in tree

Source	DF	Crook	Bow	Twist
		-----F value and significance-----		
All stud sizes combined				
Area	1	0.61 NS[1]	0.14 NS	1.46 NS
Treatment	3	0.21 NS	0.44 NS	[2]25.27**
Log position	5	5.65**	2.04 NS	20.72**
Area × treatment	3	1.86 NS	[3]3.12*	0.60 NS
Area × log position	4	1.17 NS	1.88 NS	0.69 NS
Treatment × log position	12	0.56 NS	1.23 NS	3.69**
Area × treatment × log position	12	0.76 NS	0.52 NS	5.12**
2 by 4 only				
Area	1	1.64	0.34 NS	0.63 NS
Treatment	3	0.32 NS	1.31 NS	10.21**
Log position	4	10.04**	3.77**	13.93**
Area × treatment	3	0.77 NS	2.59*	1.55 NS
Area × log position	4	1.37 NS	1.10 NS	0.48 NS
Treatment × log position	12	0.47 NS	1.20 NS	2.34**

[1] NS = Not significant.
[2] ** = Highly significant, P = 0.01.
[3] * = Significant, P = 0.05.

Table 5.—Duncan's multiple range test to evaluate the effect of treatment on warp, P = 0.05

Warp	2 by 4 only			Combined stud sizes		
	Mean	N	Treatment[1]	Mean	N	Treatment
	1/32 in.			1/32 in.		
Crook	[2]7.2	93	CC	6.2	130	CC
	6.6	94	SH	5.8	152	SC
	6.6	98	SC	5.6	149	SH
	6.1	115	CH	5.4	136	CH
Bow	7.0	93	CC	7.3	130	CC
	6.9	115	CH	7.2	152	SC
	6.1	98	SC	6.5	136	CH
	5.5	94	SH	6.0	149	SH
Twist	4.2	93	CC	4.0	130	CC
	3.1	115	CH	3.0	136	CH
	2.6	98	SC	2.1	152	SC
	1.8	94	SH	1.3	149	SH

[1] CC = conventional sawing/conventional drying; CH = conventional sawing/high temperature drying; SC = SDR live sawing/conventional drying; SH = SDR live sawing/high temperature drying.
[2] Lines connecting values indicate no significant difference between connected values.

Table 6.—Average warp and percent improvement over conventional sawing and conventional drying by treatment for second growth ponderosa pine

Warp	Combined stud size			2 by 4 Studs		
	Treatment[1]	Average	Improvement over CC	Treatment	Average	Improvement over CC
		1/32 in.	Pct		1/32 in.	Pct
Crook	SH	5.6	9.7	SH	6.6	8.3
	SC	5.8	6.4	SC	6.6	8.3
	CH	5.4	12.9	CH	6.1	15.3
	CC	6.2	—	CC	7.2	—
Bow	SH	6.0	17.8	SH	5.5	21.4
	SC	7.2	1.4	SC	6.1	12.8
	CH	6.5	9.6	CH	6.9	1.4
	CC	7.3	—	CC	7.0	—
Twist	SH	1.3	67.5	SH	1.8	57.1
	SC	2.1	47.5	SC	2.6	38.1
	CH	3.0	25.0	CH	3.1	26.2
	CC	4.0	—	CC	4.2	—

[1] CC = conventional sawing/conventional drying. CH = conventional sawing/high temperature drying; SC = SDR live sawing/conventional drying; SH = SDR live sawing/high temperature drying.

slope of grain. Table 7 lists the percent of recovery in the STUD grade, plus the improvement of the various treatments over the CC treatment. The apparent best treatment on initial measurement is CH. The yield of STUD grade material using CH varies from 73 percent for 2 by 4's only to 76.5 percent for all stud sizes. These yields are better than those reported by Arganbright et al. *(1)*, 67 percent, and Blake and Voorhies *(4)*, 45.4 percent. While the above mentioned authors indicated higher warp for moisture content below 15 percent, the studs in the study reported here were much drier, averaging 9.4 percent moisture content. The highest average moisture content was for the SC treatment; 11.5 percent.

Looking at the remeasurement data in table 7 we see that after 30 days or more storage the CH treatment showed up as best for 2 by 4's, improving slightly in yield. The SH treatment for 2 by 4's had a slight improvement in yield from 67 to 70.2 percent, and was best for combined stud sizes with 77.8 percent yield percent.

Comparing Ponderosa Pine and Yellow-Poplar

The results of this trial may have been affected by the high-temperature-drying schedule, which was not quite optimum. During the ripping operation flitches tended to pinch, indicating residual drying stresses. Any pinching results in the cut pieces warping in crook. Other evidence that some of the warp is induced by the high-temperature drying is the increase in acceptable pieces after storage. The lumber was exposed to an equalibrium moisture content of 15 to 20 percent in storage. The addition of moisture to the shell of the lumber would cause a relaxation of the stress, and removal of some warp—enough to upgrade some pieces. Alternatives for the drying schedule to alleviate the case hardening might be to lengthen the conditioning period or to reduce the wet bulb depression (less spread between dry bulb and wet bulb) during conditioning. However, it has been noted that it is difficult to adequately relieve drying stresses when the target moisture content is above 11 percent *(21)*.

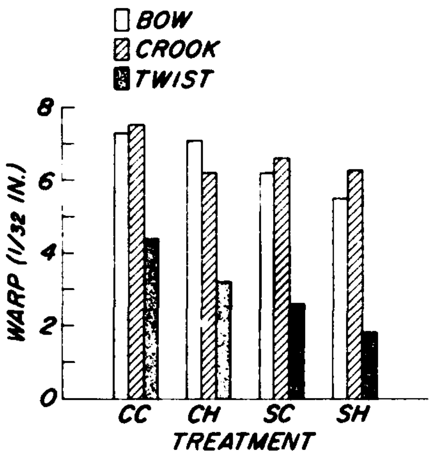

Figure 1.—2 by 4 ponderosa pine warp by treatment N = 400. CC = conventionally sawn/conventionally dried; CH = conventionally sawn/high temperature dried; SC = SDR live sawn/conventionally dried; SH = SDR live sawn/high temperature dried. (M151900)

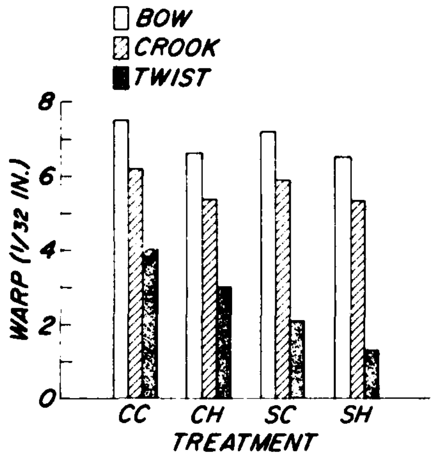

Figure 2.—All stud sizes combined ponderosa pine warp by treatment N = 567. CC = conventionally sawn/conventionally dried; CH = conventionally sawn/high temperature dried; SC = SDR live sawn/conventionally dried; SH = SDR live sawn/high temperature dried. (M151901)

While the results are encouraging compared to other research on second growth ponderosa pine, they are not as encouraging as the results from yellow-poplar. For example, average SH crook was about 6/32 in. and average SC crook about 6/32 in. for ponderosa pine, but less than 1/32 and 2/32 in. respectively for yellow-poplar. Average bow for SH and CH are respectively 6/32 and 7/32 in. for ponderosa pine, but about 5/32 and 6/32 respectively for yellow-poplar. And, average twist for SH and SC are about 1/32 and 2/32 in. for ponderosa pine, but 1/32 in. for yellow-poplar.

The contrasts are also great when comparing the percentage of pieces making STUD grade. The data in table 7 show the SH and SC treatments yielding 67.0 and 75.0 percent STUD grade pieces respectively. For yellow-poplar the SH and SC treatments yielded 100 and 98.3 percent, respectively. Achieving acceptable grade limits for moisture content was no problem with the yellow-poplar.

Anatomical Problems
The SDR process was developed to reduce the effects of longitudinal growth stresses on warp in studs. The success with hardwoods lies to a large measure in the regularity of stress distribution within trees and logs. The stresses are high in tension at the periphery of the tree, decreasing to a neutral zone and then changing to compression stress which is maximized at pith. When live-sawn flitches are cut for SDR, the stresses are balanced and restrain the tendency for the flitch to crook. However, as noted by Jacobs *(11)* the conifers don't display such clear stress patterns. Jacobs states that, while all trees have tension stresses at the periphery, the conifers may or may not have compression stresses at the pith. He continues by saying that the only tissue demonstrating compression may be reaction wood.

It may well be that the principal difficulty in sawing and drying young growth ponderosa pine is directly related to anatomical properties of the wood and not to growth stresses. As mentioned earlier, black jack pine has considerable juvenile core and is prone to have compression wood.

Juvenile wood of conifers has several negative characteristics such as high fibril angles, lower density, and shorter fibers than mature wood. These characteristics tend to result in greater longitudinal shrinkage than more mature wood and therefore more warp *(22)*. These characteristics are not as easily manipulated as growth stresses.

The other factor, compression wood, is not easily manipulated either. It, too, results in greater longitudinal shrinkage and warp when unbalanced with normal wood *(21)*.

Perhaps a better yield of studs could be achieved through using heavy top weights, serrated kiln sticks, a modified kiln schedule, and the SDR process.

Warp in Relation to Log Position
Mean warp values by log position in the tree are listed in table 8 by warp type.

For average crook, the warp is nearly in progression from butt (log 1) to top (log 5), log 3 having the lowest crook. Duncan's multiple range test indicates that log 1 has significantly more crook than the other logs, and that the other logs are not significantly different from one another.

Table 7.—Percent of pieces making stud grade based on warp and the percent of improvement over the CC treatment

Measurement	2 by 4 Studs			Combined stud sizes		
	Treatment[1]	Stud grade	Improvement over CC	Treatment	Stud grade	Improvement over CC
		------Pct------			------Pct------	
Initial[2]	SH	67.0	11.3	SH	74.5	11.4
	SC	69.4	15.3	SC	75.0	12.1
	CH	73.0	21.3	CH	76.5	14.3
	CC	60.2	—	CC	66.9	—
Second[3]	SH	70.2	12.7	SH	77.8	16.3
	SC	64.3	3.2	SC	70.4	5.2
	CH	73.9	18.6	CH	77.2	15.4
	CC	62.3	—	CC	66.9	—

[1] CC = conventional sawing/conventional drying. CH = conventional sawing/high temperature drying; SC = SDR live sawing/conventional drying; SH = SDR live sawing/high temperature drying.
[2] Measured directly after machining.
[3] Measured after 30 days or more storage in an open sided shed.

Table 8.—Duncan's multiple range test to evaluate the effect of log position in tree on warp, P = 0.05.

Warp	2 by 4 Only			Combined stud sizes		
	Mean	N	Log position[1]	Mean	N	Log position
	1/32 in.			1/32 in.		
Crook	10.4	138	1	8.2	201	1
	[2]5.4	106	2	4.8	61	4
	4.6	48	4	4.7	156	2
	4.1	14	5	4.2	18	5
	3.8	94	3	3.9	130	3
Bow	11.0	14	5	9.9	18	5
	7.6	48	4	8.6	61	4
	7.0	138	1	7.3	201	1
	5.5	106	2	6.0	130	3
	5.2	94	3	5.9	156	2
Twist	6.4	14	5	7.1	18	5
	4.4	48	4	3.9	61	4
	3.2	94	3	2.8	130	3
	3.1	106	2	2.4	150	2
	1.8	138	1	1.5	201	1

[1] 1 = butt, 5 = top.

[2] Lines connecting values indicate no significant difference between connected values.

For average bow there is no regular progression of means with log position. For combined stud sizes the top two logs of the trees had higher bow, while logs 2 and 3 had the lowest bow, and the butt logs were in the middle, but there were no significant differences. For 2 by 4's only, Duncan's test shows logs 4 and 5 are not significantly different from each other, nor are logs 1 through 4. But, log 5 has significantly more bow than logs 1, 2, and 3.

A reverse progression is found for twist, with more twist in the upper logs than in the butt log. Duncan's test, for 2 by 4's only, indicates a significant difference between all means except for logs 2 and 3, which are not significantly different from each other. For combined stud sizes logs 4 and 5 are not significantly different from each other nor are logs 2 and 3. Log 1 has significantly lower twist than the other logs (fig. 3).

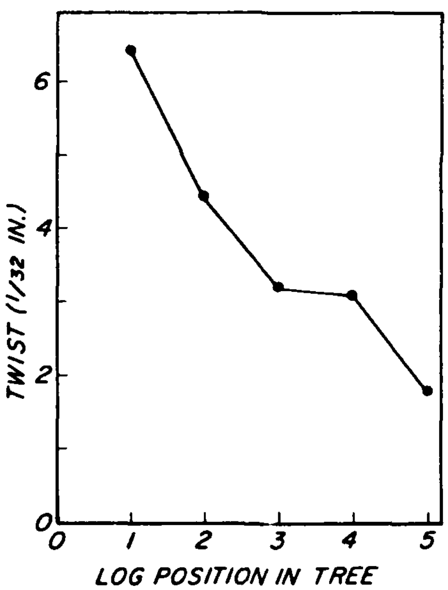

Figure 3.—2 by 4 ponderosa pine twist by log position N = 400. (1 = butt, 5 = top.) (M151902)

These data agree with the findings of Blake and Voorhies *(3)* and Hallock *(7,9)* that show butt logs have more crook, moderate bow, and less twist than upper logs.

Summary and Conclusions

The SDR process, originally designed to manufacture studs from low- and medium-density hardwoods, was evaluated for use with warp-prone young-growth ponderosa pine. Compared to the results reported by Arganbright et al. *(1)* and Blake and Voorhies *(4)*, the SDR process yielded more STUD grade lumber from young growth, "black jack" ponderosa pine. Arganbright et al. reported 67 percent STUD grade, Blake and Voorhies reported 45.4 percent STUD grade, while the study reported here had 76.5 percent STUD grade pieces (77.8 pct after storage). Both Arganbright et al. and Blake and Voorhies showed that material dried below 15 percent moisture content warped considerably more; our results are for studs dried to an average moisture content of 9.4 percent.

From this study we have concluded:

1. SDR, with some additional modifications to the drying schedule with heavy top loading, and with serrated kiln sticks, may be an economical approach to utilizing warp-prone young-growth ponderosa pine.
2. The sources that accentuate warp in studs from "black jack" pine are primarily juvenile wood and compression wood, which are anatomical problems, not growth stress problems in the normal sense.
3. It is possible to dry studs from "black jack" pine below 15 percent moisture content and still produce quality studs.
4. Butt logs produce more crooked studs than do upper logs, but fewer twisted studs.

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The saw-dry-rip (SDR) method produced substantially higher yields of STUD grade material (77.8% meeting grade) than is produced by conventional processing or than has been produced in other studies using young-growth ponderosa pine.

Keywords: Ponderosa pine, lumber, studs, saw-dry-rip, warp, live sawing, high-temperature drying.

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